NATION SHALL SPEAK PEACE UNTO NATION

RESEARCH DEPARTMENT

The Subjective Grey Scale Related to Television Transfer Characteristics

Report No. T.050

Serial No. 1954/35

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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SUMMARY

A physiological scale of subjective impressions of brightness is measured in terms of physical scales of luminance. It is found that four criteria of brightness are fairly uniformly spaced along the physical scale when luminance is expressed in logarithmic units. The report confirms that it is preferable to plot the transfer characteristic of a television system in logarithmic units rather than linear units. Quantitative data are presented on the extent of the various regions in the grey-scale for a range of surround adaptations.

1. INTRODUCTION.

When the overall transfer characteristics of a television system are being considered, the end product of the physical chain is the pattern of luminance produced on the phosphor of a television monitor. This pattern is viewed by human eyes which transmit messages to the brain and further transfer characteristics, which might be called "the human element", are involved in this process. Where the monitor tube luminance is low, the pattern element might be judged "black", and where the luminance is high, the element might be judged "white" by a person whose eyes and brain have a certain transfer characteristic. This human characteristic is not a static one, however, and under different conditions, a luminance referred to as "white" in one context may be considered to be "grey" in another context, although a physical photometer would give the same indication in both cases. Thus, there is a fundamental difference between a human observer and a mechanical device for measuring brightness. Whilst it is necessary to measure the luminances appearing on the face of a television monitor with a physical photometer in order to ascertain the transfer characteristics of a system and assess its performance relative to other systems, it is also necessary to know how the pattern of luminances on the monitor tube face will appear to the average viewer, before a final assessment of performance can be completed.

It is possible to illustrate the physical characteristics of a television system with the aid of graphs drawn to scales which may appear to give a fairly uniform weighting over the range of physical units measured. Under normal conditions of television viewing, the range of physiological measurements may, however, be

compressed at one end of a particular physical scale, and a different physical scale might enable a much clearer picture of the physiological aspect to be obtained. In the case of a television system transfer function, a scale of channel output voltage is used on the ordinate and a scale of physical luminance of tube phosphor on the abscissa.

The following investigation has been designed to enable the subjective location of black, greys and white to be estimated in terms of physical measures of luminance and indicated, at least approximately, along the abscissa scale of the overall transfer characteristics of television systems. Such terms as "black crushing" and "white crushing" can then be related to the physiological scale and given greater significance than is possible on a purely physical scale.

2. EXPERIMENTAL.

A television picture screen was simulated by a piece of back-illuminated opal perspex, size 10 in. × 8 in. (25 cm × 20 cm), set in the centre of a white board, 30 in. square (76 cm). Nine test patterns, of size 2·13 in. × 1·6 in. each (5·4 cm × 4·1 cm), were spaced out in the picture area, the gaps between them varying from 0·8 in. to 0·9 in. in width (2·0 cm to 2·3 cm). When this arrangement was viewed at a distance of four times the picture height, therefore, the visual angles involved were as follows:

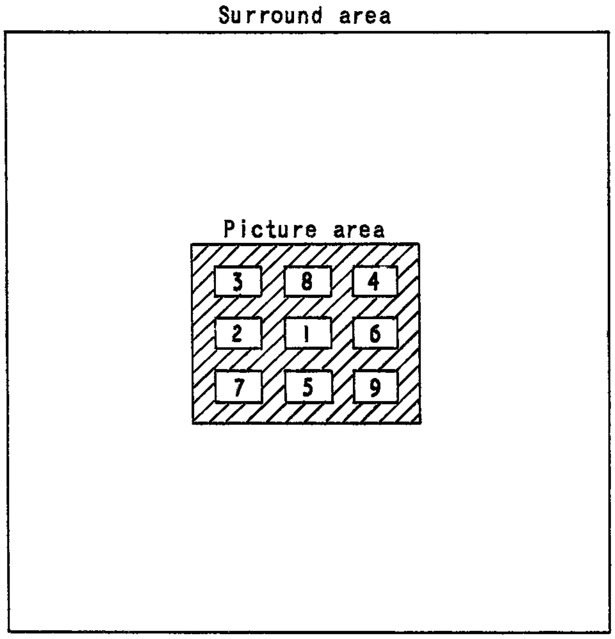
Outside dimensions of white screen	$56^\circ \times 56^\circ$
Total "picture" area	$19^\circ \times 15^\circ$
Test-patch area (each)	$4^\circ \times 3^\circ$
Inter test-patch spaces, width	from $1{\cdot}5^\circ$ to $1{\cdot}7^\circ$

A second set of nine test-patches of size 0·5 in. × 0·5 in. (12·7 cm × 12·7 cm) replaced the larger ones in the picture area, for some further observations. The visual angles involved now become:

Test-patch area (each)	$1^\circ \times 1^\circ$
Inter test-patch space, width	from 3° to 4°

The viewing room was illuminated by a single 40-watt tungsten lamp in a ceiling pendant fitting which hung behind the viewers. This lamp provided a low level of general illumination considered suitable for television viewing. The luminance of the white screen surrounding the "picture area" was approximately ½ ft-lambert.

The picture area represented by the opal perspex was illuminated to a luminance of 1·32 log ft-lamberts (21 ft-lamberts, 226 asb). Table 1 lists the densities of the neutral filters which were placed in random order over the nine test-patch areas in order to modify their luminances. Fig. 1 illustrates the appearance of the test screen and the distribution of the neutral densities over the $4^\circ \times 3^\circ$ size test-patch areas. A different, random, distribution was used over the $1^\circ \times 1^\circ$ size test-patch areas.



Test patches numbered 1-9

(see Table 1 for luminance values)

Fig. 1 - Simulated television picture screen containing 9 test-patches

TABLE 1

Test-Patch	Filter Density	log ft-lambert	ft-lambert	asb
1	1·90	$\bar{1}$·42	0·26	2·8
2	1·40	$\bar{1}$·92	0·83	8·9
3	1·32	0·00	1·0	10·7
4	1·11	0·21	1·6	17
5	0·81	0·51	3·2	34
6	0·50	0·82	6·6	71
7	0·18	1·10	12·6	135
8	0·03	1·29	19·5	210
9	0	1·32	21·0	226

The luminance of the spaces between the test-patches was also modified by the insertion of neutral density masks. Observations were made under the following conditions:

TABLE 2

Test-Patch	Size of Test-Patch	Luminance of Spaces between Test-Patches (log ft-lamberts)	(log asb)
1	$4^\circ \times 3^\circ$	less than $\bar{2}$·0	less than $\bar{1}$·03
2	$4^\circ \times 3^\circ$	$\bar{1}$·42	0·45
3	$4^\circ \times 3^\circ$	0·21	1·34
4	$4^\circ \times 3^\circ$	1·32	2·35
5	$1^\circ \times 1^\circ$	less than $\bar{2}$·0	less than $\bar{1}$·03
6	$1^\circ \times 1^\circ$	0·45	1·48
7	$1^\circ \times 1^\circ$	1·32	2·35

Viewers were allowed to inspect a particular arrangement of test-patches and neutral density surround-mask, standing at approximately 3 ft (1 m) (4 × picture height) from the screen. They were given a diagram of the picture area containing the nine test-patches and were invited to write in each of the nine blank rectangles the category into which they would place each area. The only four categories allowed were white, light grey, dark grey or black, but viewers were told that although they were not allowed to use any additional category, they need not necessarily use all these four categories when completing the form. When fifteen viewers had completed the forms for the first arrangement, the experiment was repeated with a second arrangement and so on until all seven sets of conditions outlined in Table 2 had been observed.

3. RESULTS.

With some test-patch luminances seen in a specific context, all the viewers used the same term, for example, "dark grey". In some instances, however, there was a division of opinion. Some viewers might call a test-patch dark grey and others would decide it was black. A system of marking was used, whereby the name "black" scored 0, "dark grey" 1, "light grey" 2 and "white" scored 3. The total score for

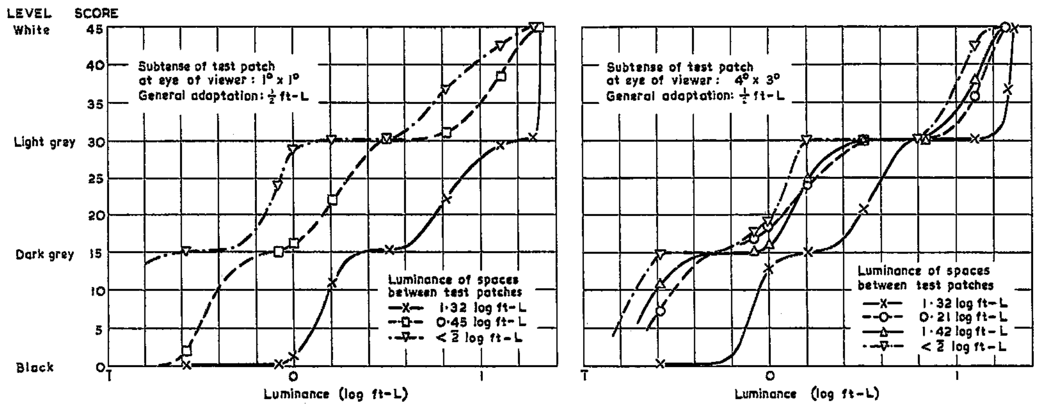


Fig. 2 - Average opinions of 15 viewers on appearance of test-patches viewed in various contexts

each test-patch luminance was summed for the fifteen viewers and in Fig. 2 the scores have been plotted against the logarithm of test-patch luminance. Complete agreement amongst all the viewers on the four criteria of black, dark grey, light grey and white will give scores of 0, 15, 30 and 45 respectively. There are seven sets of curves relating to the seven conditions set out in Table 2. Each curve exhibits transitional regions between luminances where all viewers are agreed that the test-patch is white, light grey, etc., in that particular context. It has been assumed that the mid-point of such a transition is the point at which a test-patch changes in appearance from, say, white to light grey. The luminance of this point is considered to be the borderline between two physiological levels. These intermediate luminances, Table 3, have been plotted against the inter-test-patch luminances in which they were viewed when they became the changeover point from one subjective criterion to another, Fig. 3. It can be seen that when the test-patches are fairly large (4° × 3°) the borderlines between the different criteria are more or less independent of the

luminance of the immediate surround until that surround attains quite high values, of the order of 5 or 10 ft-lamberts (50–100 asb). When the test-patches are much smaller ($1^\circ \times 1^\circ$) the luminance of the immediate surround has a much greater influence on their subjective appearance.

TABLE 3

Change of Criterion from:	Inter Test-Patch Luminance (log ft-lambert)					Test-Patch Size
	1·32	0·45	0·21	$\bar{1}$·42	less than $\bar{2}$	
Black to Dark Grey	$\bar{1}$·91		$\bar{1}$·43	$\bar{1}$·32	$\bar{1}$·17	$4^\circ \times 3^\circ$
Black to Dark Grey	0·13	$\bar{1}$·53			–	$1^\circ \times 1^\circ$
Dark to Light Grey	0·55		0·17	0·17	0·05	$4^\circ \times 3^\circ$
Dark to Light Grey	0·83	0·22			$\bar{1}$·90	$1^\circ \times 1^\circ$
Light Grey to White	1·29		1·13	1·10	1·04	$4^\circ \times 3^\circ$
Light Grey to White	1·31	1·08			0·86	$1^\circ \times 1^\circ$

$\log_{10}$ asb = $\log_{10}$ ft-lambert + 1·03

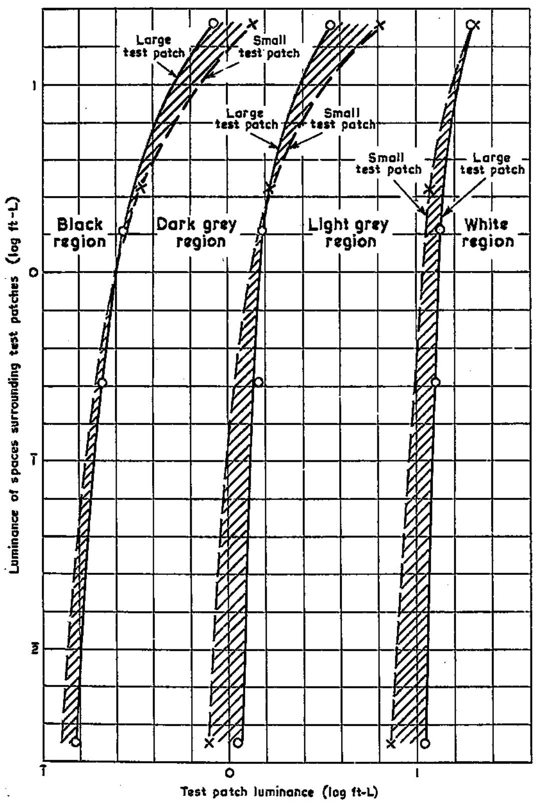


Fig. 3 - Regions of luminance over which 4 criteria of subjective brightness are maintained

It is difficult to choose a representative value of luminance for the spaces between the test-patches and assume that this value will be functional under normal conditions of viewing. Any object appearing on the screen may vary in size from the smallest detail of the order of 1′ arc to the largest object that almost fills the screen, of the order of 18° arc. It can be surrounded by an area that may be of any luminance from the lowest to the highest attainable on a tube, from black to peak white. The amount of illumination in the viewing room will also influence the judgment of an observer, but these measurements have been made assuming a moderately low level of the order of ½ ft-lambert of ambient light. In order to derive some practical measure of use from the present data, a nominal average value has been taken from each pair of curves which indicate a physiological borderline between the criteria. Very approximately the borderline between black and dark grey is $\bar{1}$·3 log ft-lamberts (0·2 ft-lamberts, 2·1 asb); between dark grey and light grey it is 0·0 log ft-lamberts (1 ft-lambert, 10·7 asb); between light grey and white it is 1·0 log ft-lamberts (10 ft-lamberts, 107 asb). These are values which can be considered valid if the eye is adapted to a general illumination of ½ ft-lambert (5 asb).

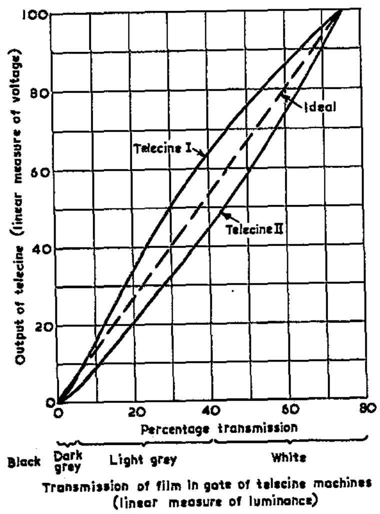


Fig. 4 - Linear representation of transfer characteristics

These values may now be applied to the practical case of two telecine machines which were thought to be "black crushing". Fig. 4 shows the output voltage plotted on a linear ordinate. The transmission of film in the gate gives a linear measure of input luminance along the abscissa. An ideal case of a cathode ray tube with constant gamma of 2·5 has been assumed. The physiological sensations of black, dark and light grey and white are also shown along the abscissa. It is difficult to see from the curves whether some "black-distortion" is taking place. However, on inspection of the physiological scale, it can be seen that the black and dark grey sensations occupy very little space on the diagram and only light grey and white are given ample length along the abscissa. It is therefore not possible to see what is happening to the dark regions from this diagram.

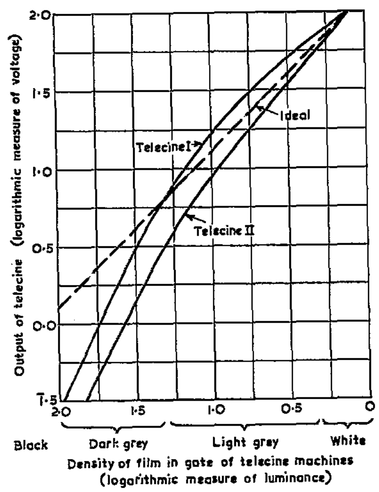


Fig. 5 - Logarithmic representation of transfer characteristics

In Fig. 5 a measure of the output voltage has been made on a logarithmic ordinate scale. The density of the film in the gate gives a logarithmic measure of input luminance along the abscissa. The curves, drawn from the same data as Fig. 5, now show quite clearly that the two telecine machines are "black-stretching", when an ideal cathode ray tube of constant gamma of 2·5, is assumed. The physiological scale along the abscissa is well spread out, and indicates that the curves become steeper when the appearance of the pattern in the film gate changes from light grey to dark grey. A relatively large change in output voltage can be seen to take place for a relatively small change in luminance. The influence of noise on the appearance of the blacks has been omitted.

This analysis has assumed that the output of the telecine will be terminated in an ideal cathode ray tube, of constant gamma of 2·5 over the full range of voltages and luminances involved. The range of output voltage represented in Figs. 4 and 5 is of the order of 300 to 1; in practice no television tube could operate uniformly over this range. It would be more reasonable to assume a working range of the order of 30 to 1. Outside these limits the response of the cathode ray tube would be a constant, independent of the voltage applied. This effect would be illustrated in Fig. 5, for example, by drawing a horizontal line across the diagram at the value of 0·5 on the ordinate scale. The curves of the two telecine machines, modified by this

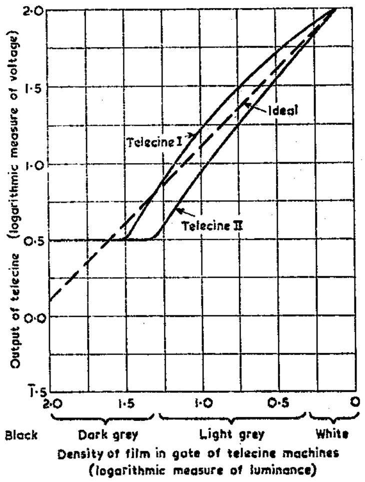


Fig. 6 - Logarithmic representation of transfer characteristics including C.R.T. limitations

limiting line, are shown in Fig. 6. It can be seen that the steeper the original curve, derived by assuming an ideal cathode ray tube, the longer will be the horizontal portion resulting from practical limitations of phosphor output. Thus, the greater the "black-stretching" intrinsic in the telecine equipment, the greater in practice will be the black-crushing resulting from the limitations of operation of the cathode ray tube. Fig. 6 illustrates that in practice "black-crushing" is extending into regions of the picture normally regarded by viewers as being "dark grey", and in the case of Telecine II almost extends to the "light grey" areas.

4. CONCLUSIONS.

If the transfer characteristics of a television system are plotted in logarithmic units, the corresponding subjective physiological scale is then opened out and the implications of changes in slope of a curve may be readily assessed. Physiological responses are known to correspond more closely to the logarithm of a stimulus than to the arithmetic amplitude of the stimulus (Weber-Fechner law). This work confirms that a subjective subdivision of a set of luminances into four criteria, viz., black, dark grey, light grey, and white, is distributed with reasonable uniformity over a logarithmic scale of luminance, and establishes the extent of the regions over which the criteria apply.